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Assessing energy sustainability of rural communities using Principal Component Analysis

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ABSTRACT

Engaging communities to action under the new climate change regime and fostering citizens to adopt sustainable energy patterns, remains still a challenge. A new impetus for commitment was put in place for local regions, through the Covenant of Mayors (CoM) initiative by the EU communities. The key challenge is the penetration of Renewable Energy Sources (RES), since most rural communities have vast unexploited RES potential (solar, wind, biomass, etc.). RES promotion could also specifically support rural communities' challenges as regards growth, jobs and sustainability, which are also aggravated by the current financial and economic crisis.

One of the most significant steps throughout participating in this initiative is the evaluation of the community's sustainable energy status. Aim of this paper is to assess rural communities' energy sustainability using the Principal Component Analysis (PCA), based on the outputs of two European "Intelligent Energy For Europe" projects on the following regions: Mountainous and Agricultural Communities and Islands. Appropriate customization of the PCA will be elaborated, to aggregate sustainability indicators, capture related interactions and interdependences. The results of this study can support the monitoring of such communities' progress, which is an especially valuable parameter as concerns the development and mainly implementation of their Sustainable Energy Action Plans.

Contents

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1. Introduction

The European Union (EU) is currently leading the global fight against climate change. The European Council has launched the new European Strategy ("20-20-20" package for 2020) for sustainable development [1], in order to make the EU the most competitive and dynamic economy in the world, knowledge-based, able to maintain economic growth with more and better jobs, as well as greater social cohesion [2].

Engaging communities to action under the new climate change regime and fostering citizens to adopt sustainable energy patterns, especially for the stimulation of the Renewable Energy Sources (RES) and Rational Use of Energy (RUE) practices' penetration, remains still a challenge [3,4]. Community-level is crucial for energy sustainable development, as being closest to the final consumer. Moreover, creation of benefits for the local population, companies and politicians can be considered as a win–win situation for all involved actors. Most rural communities have vast unexploited RES potential (solar, wind, biomass, etc.). RES promotion could also specifically support rural communities' challenges as regards growth, jobs and sustainability, which are also aggravated by the current financial and economic crisis.

According to the United Nations [5], rural regions (areas outside of large cities and towns) consist of 32% of Eastern, 17% of Northern, 34% of Southern and 17% of Western Europe's population, but cover 90% of Europe's land surface (based on population density) and therefore have considerable importance, particularly with regard to new policies for sustainable development and clean energy technologies.

Some rural communities, and in particular those which are most remote, depopulated or dependent on agriculture, already face particular challenges as regards growth, jobs and sustainability. These challenges include lower income levels, an unfavorable demographic situation, higher unemployment rates, a slower development of the tertiary sector, weaknesses in skills and human capital, a lack of opportunities for young people and a lack of necessary skills in parts of the agricultural sector and food processing industry. Furthermore, rural areas generate 45% of gross added value in EU-27 and 53% of the employment, but tend to lag compared to predominantly urban areas. In EU-27 the income per capita of predominantly urban areas is almost double to that of predominantly rural areas [6].

As a result, these areas do not posse adequate capacity to implement Sustainable Energy Actions Plans (SEAPs) and promote RES and RUE applications towards the development of sustainable energy communities. In particular, some typical problems in the route towards the sustainable energy development in rural communities are [7–11]:

- Lack of technical capacity and resources.
- Lack of direct initiatives at local/regional authority level.
- Unawareness to the state-of-the-art, potential benefits, best practices and successful applications.
- The experience and best practices of energy sustainable development has not been systematically disseminated yet in these communities.
- Misconceptions of related local key actors (developers, architects and facilities' managers) about new or unfamiliar technologies – difficulties in achieving economies of scale, as in the case of the major cities or territories with urban characteristics.
- Poor understanding of the broader community that the cost of inaction is far more than the cost of action and of the development opportunities arising from sustainable energy investments for the region.

One of the most important initiatives to support these communities in this effort is the Covenant of Mayors (CoM), which through the Joint Research Centre supports the communities with methodologies and tools for the preparation of their Sustainable Energy Action Plan – SEAP [12]. Tools and methodologies developed so far include guidelines for drafting action plans and monitoring SEAP's implementation progress through a series of indicators. Although these indicators are very detailed and cover a large variety of sectors (social, technological, economic, and environmental), they are not tailor made to the specificities of the rural communities (mountainous, agricultural, island). To this end, a methodological approach was introduced within the framework of the EACI funded project "Renewables and Rational Use of Energy Stimulation in Mountainous/Agricultural Communities towards Sustainable Development" for the identification of few but concise indicators for rural communities. These indicators can serve as the basis for the calculation of an Energy Sustainability Index, based on which the communities' categorization as "basic", "medium" or "advanced" level regarding their sustainable development experience can be realized. This is an especially useful tool at the initial steps of the SEAP's development, since the community leaders can decide on the best combination of actions and technologies that can appropriately support their development, depending on their advancement level.

The development of Energy Sustainability Indexes for the evaluation and support of policy making is existent in the international literature. Brown and Sovacool [13] propose the creation of an Energy Sustainability Index to inform policymakers, investors, and analysts about the status of energy conditions in the United States, Abouelnaga et al. [14] study the nuclear Energy Sustainability Index, while Afgan et al. [15] focus on the modeling of the energy system's sustainability index. To the best of our knowledge, an Energy Sustainability Index on a community level is not present in the literature.

Aim of this paper is to assess rural communities' energy sustainability using the Principal Component Analysis (PCA), based on the outputs of two European "Intelligent Energy For Europe" projects on the following regions: Mountainous and Agricultural Communities and Islands. Appropriate customization of the PCA will be elaborated, to aggregate sustainability indicators, capture related interactions and interdependences. The results of this study could also support the monitoring of such communities' progress, which is an especially valuable parameter as concerns the development and mainly implementation of their SEAPs.

To this end, the paper is structured along the following sections:

- Section 2 outlines the development of the Energy Sustainability Index, using the Principal Component Analysis (PCA).
- Section 3 provides an overview of the case study communities, namely mountainous/agricultural and island communities.
- Section 4 presents the results and provides their analysis.
- Section 5 summarizes the manuscript's conclusions.

2. Energy Sustainability Index based on PCA

2.1. Theory

The history of sustainability definition and assessment is short (since the 1990s) but the effort towards capturing its essence is quite intense. Several approaches have been proposed to test the sustainability of a region. Examples are: Pressure-State-Response model, Ecological Footprint, Barometer of Sustainability, Environmental Sustainability Index, Sustainability Assessment by Fuzzy Evaluation, Multi Criteria and Fuzzy Logic, etc. [16].

One common characteristic of these approaches is the use of a number of indicators that depict progress in sustainable

development, called Sustainable Development Indicators (SDIs). According to Singh et al. [17], indicators and composite indicators are increasingly recognized as a useful tool for policy making and public communication in conveying information on countries' performance in fields such as environment, economy, society, or technological development. Warhurst [18] considers measuring of sustainable development as a two-step approach, where the first step measures the progress made in a number of selected individual fields by SDIs, while the second step focuses on the overall progress made towards sustainable development through a combination of these individual fields with regards to their interlinking.

For the construction of the SDI per thematic field, the use of a multivariate method is required, in order to deal with the simultaneous treatment of a series of variables. Some of the techniques used for the construction of the SDIs include Factor Analysis, Principal Component Analysis, Cluster Analysis, Multivariate Analysis of Variance, etc.

Principal Component Analysis (PCA) is a method frequently used among multivariate techniques to construct SDIs. The central idea of PCA is to reduce the dimensionality of a data set consisting of a number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming it into a new set of variables, the Principal Components (PCs), which are uncorrelated, orthogonal and ordered so that the first few retain most of the variation present in all of the original variables. In summary, it can be said that PCA is a variable reduction technique that can be used when variables are highly correlated; it reduces the number of observed variables to a smaller number of PCs that account for most of the variation of the observed variables and is a large sample procedure [19]. Moreover, PCA has the advantage of being sensitive to the relative scaling of the original variables. These characteristics are the reasons why researchers use PCA to construct their SDIs.

PCA is mostly used as a tool in exploratory data analysis as well as for developing predictive models. PCA has encountered so far a wide range of applications as far as local communities are concerned, both urban and rural but also at prefecture, region or country level. More specifically, PCA has been used to typify the 74 autonomy units of Shizuoka and analyze their agricultural trend [20]. Tsatsarelis et al. [21] have used it as an assessment tool to estimate the status of open dumps in Laconia prefecture of Peloponnese in southern Greece, where all open dumps were targeted for closure by 2008. PCA methodology has further been utilized in the evaluation of Integrated Innovation Capabilities of Regions of Canada resulting to policy recommendations to provide better ideas for economic development of each separate region [22].

Hybrid models including PCA in conjunction with other methodologies have also been introduced. For example in the Twin Cities Metropolitan Area of Minnesota urbanization has been measured and modeled using PCA in conjunction with Geographically Weighted Regression (GWR) [23]. Moreover, PCA has been used together with data envelopment analysis (DEA) to evaluate the Urban Sustainable Development Levels on the seventeen cities in Shandong Province, as the rapid acceleration of industrialization and urbanization influenced urban ecological environment and resource utilization [24].

Research including PCA has also been conducted as far as economic and social aspects of communities are concerned. PCA has been extensively used in order to construct socio-economic status indicators in certain communities of the United Kingdom [25]. The Mexican Government has used the PCA methodology in order to disaggregate poverty measures to the community level. Similarly, Columbia University is using PCA in ongoing joint work to construct a poverty map for Costa Rica [26].

Additionally, many research groups measured the concept of vulnerability that the European energy systems exhibit [27–31], using PCA. Additionally, Chevalier [33] used several indicators in order to measure the dependency that countries within the European Union exhibit to oil and natural gas.

Nevertheless, to the best of our knowledge, PCA has so far not been used to evaluate the energy sustainability of rural communities. Using the PCA, the Energy Sustainability Index for eight rural (mountainous, agricultural, and island) communities will be examined.

The general form of the model that will be used for the development of the Energy Sustainability Index is presented below:

$$\mathrm{ESI} = \alpha + \beta_1 X_1 + \cdots + \beta_K + X_K + e \tag{1}$$

where X_1, X_K are set of the proposed indicators that were used for capturing and quantifying the main elements that define the energy sustainability of the communities under examination. Additionally, β_1, β_k are the corresponding vectors of parameters in each domain, and e is the error term.

2.2. Calculations

Having presented the general form of the model, the development of the Energy Sustainability Index for each community will be realized based on Eq. (2).

$$\mathrm{ESI}_k = \beta_1 X_{1k} + \beta_2 X_{2k} + \cdots + \beta_8 X_{8K} + \beta_9 \beta_{9K} + e \tag{2}$$

where X_1, X_K are (as mentioned above) set of indices that will measure the sustainability index, β_1, β_2 the corresponding vectors of parameters and ε is the error factor.

The total variation in the index is composed of: (i) the variation due to sets of indicators, and (ii) the variation due to error. If the model is well specified, including an adequate number of indicators in each domain, so that the mean of the probability distribution of ε is zero, ($E(\varepsilon) = 0$), and error variance is small relative to the total variance, we can reasonably assume that the total variation in the two indices is largely explained by the variation in the indicator variables in each domain included for the computation of this composite index.

The application of PCA in the data consists of multiple steps.

First, normalization of the selected indicators is carried out and afterwards they are positively related with energy sustainability with the following equation:

$$x_{ik} = \frac{X_{ik} - Min(X_i)}{Max(X_i) - Min(X_i)} \tag{3}$$

The above adjustment transforms all the selected variables on the 0–1 scale. The value of 0 is assigned to the community with the lowest value of the energy sustainability indicator and value of 1 is assigned to the community with the highest value of the selected indicator.

Continuously, the correlation matrix (R) of the indicators is calculated which depicts the interrelations of the indexes. If an element of this matrix is close to 1 (or −1) then the corresponding indicators are strongly related positively (or negatively), which means that only one of them will be considered in the variation. On the other hand, if a point in the matrix is close to 0 then the respective indices are uncorrelated and the method takes both under consideration in the variation.

The next step is to calculate the eigenvalues and eigenvectors of the correlation matrix. The main intuition behind the calculation of the eigenvalues is the usage of the following determinant equation:

$$(R - \lambda I) = 0 \tag{4}$$

where R is the correlation matrix ($n \times n$), λ is the symbol for eigenvalues and I is the unit matrix.

Solving for λ, a nth degree polynomial equation is obtained and n eigenvalues which correspond to the correlation matrix R are

calculated. The eigenvalue with the largest rate is the one that holds most of the variation and the eigenvalues with very small rate are usually ignored and the solution of the problem is getting simpler.

Furthermore, in order to derive the eigenvectors the following matrix equation is solved:

$$(R - \lambda_j I)F_j = 0 \tag{5}$$

where R is the correlation matrix, λ_j is the corresponding eigenvalue, I is the unit matrix and F_j is the matrix of the eigenvector corresponding to the λ_j eigenvalue.

Finally, a matrix of vectors by placing the calculated eigenvectors in the columns is developed. Having formed this matrix we transpose the matrix of vectors and multiply it on the left of the original normalized indicators, transposed. By this computation, the replacement of the set of indicators by an adequate number of their Principal Components (PCs) is performed. The PCs are considered to be normalized linear functions of the indicator variables and are mutually orthogonal. The first PC accounts for the largest proportion of total variation (trace of the covariance matrix) of all indicator variables. The second PC accounts for the second largest proportion and so on.

Taking into account that $\lambda_1 = \text{var}\, PC_j$ and hence $\lambda_1 > \lambda_2 > \cdots > \lambda_j =$ total variation of the index. Thus, the Energy Sustainability Index is developed using the variances of the calculated Principal Components as weights:

$$(\text{ESI}_k) = \frac{\lambda_1 PC_1 + \lambda_2 PC_2 + \cdots + \lambda_j PC_j}{\lambda_1 + \lambda_2 + \cdots + \lambda_j} \tag{6}$$

where ESI_k is the sustainability index of the k community and $\lambda_j PC_j$ is the multiplication of an eigenvalue with its corresponding Principal Component.

A simple rearrangement of the weighted components of the Energy Sustainability Index helps to express it as a weighted sum of the normalized version of the indicators and thus, enables to express the relative importance of the respective indicators for determining the final score.

3. Case study communities

In the following paragraphs, a brief description of the examined rural (mountainous, agricultural and island) communities is elaborated.

3.1. Aphrodite Hills, Paphos – Cyprus

The Aphrodite Hills resort is a project still under development. It covers 234 ha of land; 15% is the share of ecologically sensitive (protected) area and only 8% is the build-up area. Currently the total (maximum at any time) number of inhabitants in the insular area is 4.000. As Cyprus' first fully integrated resort, it combines approximately 500 exclusive low rise residential properties (three small villages, Zephyros Village, Helios Heights Village and Orpheus Village) and a 290 room five-star hotel with 4 restaurants.

The maximum electrical load of the area is currently of the order of 2.000–3.000 kVA. Electricity consumption for space heating and cooling is currently 11.406 kWh/day and is expected to increase to 14.750 kWh/day (29.3% increase) in the near future. The current consumption of diesel for space heating is 60 tons per annum and is expected to increase to 96 tons per annum. The Current Petrol and diesel used for transportation in the Aphrodite Hills area is 800 tons per annum. RES options used are small domestic size solar thermal systems for hot water production for sanitary use, ground source heat pumps for space heating in some houses and modification of current fire places to high efficiency wood boilers [9]. Most the houses have installed solar thermal panels. A few houses use Ground Source Heat Pumps (GSHP) for space heating.

3.2. Cabras, Sardinia

The Municipality of Cabras, located in the center of the Western coast of Sardinia, in Italy (8.889 habitants, surface 102 km^2, demographic density 87 inhabitants/km^2) is rich of uncontaminated nature, history and archeological places. Its vocation is rural and coastal development; the so-called "tourism and environmental chain" is based on agriculture, fisheries, new services, marine protected area, archeological sites. The productive system is typical of a rural Mediterranean area. The Cabras area is characterized by low population density and active local, provincial, regional government.

The consumptions per person/year in the Oristano Province (in which Cabras is located) is 2.900 kWh/person/year, which is less than the national average (5.437 kWh/person/year), because the Oristano Province has few productive activities. The analysis of the main energy needs of Cabras, from 1995 to 2004, point out that the main candidate areas for the promotion of RES and RUE are the domestic and the primary sector (farming, aquaculture, fishing, etc.). Segments of increasing energy demand are the public lighting and residential sectors. The estimated energy needs for Residential heating are: 1.429 toe/y. The area's RES potential is very high, in terms of solar, small wind, biomass and biofuels.

3.3. Crete, Greece

Crete is the fourth largest island in the Mediterranean with an area of 8.335 km^2 and population that surpasses 600.000 residents (demographic density of 72 inhabitants/km^2). The complex morphology of the island is proven ideal for wind applications. In parallel, biomass-to-energy systems could play important and potentially synergistic roles in order to cover its energy needs. The island's mountainous nature combined with limited water resources in the eastern part and a harsh geological infrastructure, offers quite narrow perspectives for agricultural alternatives, such as energy crops [34].

Electric demands tend to rise by 6.0% annually; very similar to the rate in which economy grows (6.8%). Crete's demanding electric system is characterized by high demand growth rates and low load factor, so the island experiences a power inefficiency problem that was provoked by the exceptionally high peak power loads caused by seasonal variations. The major part of the produced electricity is considered safer to be served from resource and production controlled units, such as fossil fuel-based power plants (reliance on fossil fuels is close to 86% – increased by 15% compared to the national average). For years, there have been plans for the connection of the island's grid with the mainland's one, which have been finally abandoned due to difficulties (high depths and strong undersea streams between Crete and Peloponnese and seismic activity). The island's public opinion reacts fiercely against the addition of new thermal plants due to their environmental impacts (i.e. in the case of the fossil-fueled power plant of Atherinolakkos), while on the other hand RES tend to be positively assessed by the Cretan people [35,36].

3.4. Karditsa, Greece

Karditsa covers an area of 2.363 km^2, thus 18.8% of the Thessaly precinct and 2% of the nation's land in Greece, with population of the 129.541 residents [37] and a population density of 45.4 inhabitants/km^2. The region is a combination of flat and mountainous/semi-mountainous areas. The flat areas cover 47% of the prefecture with a mean altitude of 90–200 m, while the

mountainous and semi-mountainous areas cover 42% and 9% of the region respectively with an altitude ranging from 200 to 2.000 m. In addition, the 41% of the prefecture's area is rural and fallow, the 25% is rangeland and the 24% is covered by forests, while settlements, waters and rest areas take up the rest 10% [38].

As far as the community's energy sources are concerned, electrical energy, oil and gas are almost exclusively used. Total energy consumption in the region reaches 227 ktoe, while fossil fuel produced energy accounts for slightly over 90% of this amount. Electricity in the region is produced principally by lignite power stations, with the exception of the hydropower station of the Plastira Lake with 129 MW installed capacity and a small proportion of wind, biomass and solar production. Natural gas spreads rapidly with 540 km of network constructed in the area and a total of natural gas users in Thessaly of about 24.000 (up to the end of 2008) [39].

3.5. Karpathos, Greece

Karpathos is the second largest island of Dodecanese in Greece, with an area of 301 km^2 and a coastal length of 160 km. The island's shape is elongated, with a length of 48 km and a width that varies between 12 km and only 1 km in the narrower point. Mountains throughout the length of the island provide many ideal locations for wind parks. Most of the few flat extents of island are located in the southern and southern-east coast, providing an ideal locale for photovoltaic (PV) parks, while northern coasts are mainly steep and rocky.

Population in Karpathos reached 6.511 in 2001, while in Kassos, the neighboring island, reside another 990. It is estimated that during the holiday months, with the addition of both tourists, as well as Carpathians visiting their homeland, the island surpasses 20.000 residents. Population growth in the island led to a continuous increase in energy demands during the last few years, a trend that is expected to continue in similar rates [40]. Diesel-fired generator units belong to the Public Power Corporation (PPC) and fulfill Karpathos' current energy requirements; thus the region (islands of Karpathos and Kassos) forms a Stand-Alone Power System (SAPS). Apart from the established diesel generators that primarily contribute in the island's annual requirements, wind power also makes a small presence in the grid. Found in two separate locations are farms belonging to PPC and the Karpathos Public Water Company, with a total capacity of 450 kW; today, only one of the parks is functioning, contributing with a mere 275 kW of capacity.

3.6. Murau, Austria

Murau is one of the three districts of the Region of Styria, Austria. The surrounding area is mountainous with a highest peak of 2500 m. The basic economy and settlement centers (Judenburg, Zeltweg, Fohnsdorf and Knittelfeld) are located inside the Alpine Aichfeld-Murboden basin, far away from commercial centers (Wien, Salzburg). Murtal motorway has favored access to Judenburg and Knittelfeld. In contrast, northern municipalities are rather disadvantaged. There is also a rail link the western part of the region through Vienna. The area is characterized by low population density, 23 inhabitants/km^2. According to the population census conducted in 2001, 109.351 persons live in the Murau, Judenburg and Knittelfeld municipality groupings. According to the ÖROK-population forecast 2001–2031, a decline of 4.2% in the population has been predicted.

Murau has set a goal for complete self-sufficiency. There are several local Energy Service Companies (ESCOs), a natural gas grid, while the district heating networks of Judenburg and Knittelfeld are owned by foreign companies. There are also some small private hydro power and CHP plants, as well as the highest wind park in the Alps and a biogas system. Murau produces more electricity than its inhabitants' needs. RES cover approximately 30% of the local needs, amounting up to 88 ktoe. In the heating sector, extensive use of biomass is taking place, while gas heating and waste-heat also exist in some areas. Murau district is off the gas grid [41,42].

3.7. Rõuge Municipality, Estonia

Rõuge rural municipality lies in Võru County of Estonia and is 273 km far from Tallin. The overall land that the municipality covers is 263.7 km^2 with a diversity of arable land (20%), grassland (8%) and forest land (57%). Almost 2.286 inhabitants live in Rõuge's area, with the population density being very low, namely 8.7 inhabitants/km^2, while the income per person is below Estonian average (4.866 euros). Rõuge, located on the north-eastern side of Haanja uplands, is very rich in lakes and valleys [43].

There is an energy park in Rõuge rural municipality, which was established in 2001 in order to educate the region to be fossil-fuel free, while there is large biomass potential. The current share of biomass for heating purposes in municipality premises is already 100%. There are five hydro stations in operation, which in full working status could produce the 15% of the municipality's electricity needs. The region may have a moderate solar, wind as well as geothermal energy potential, but the overall contribution of RES to the total energy consumption barely exceeds 13%. Housing and tertiary sector is the most energy consuming, followed by transportation, industry and farming. The municipality struggles to implement the use of green energy, by updating old hydro-electric stations and reducing energy consumption in public buildings, however the local leaders are faced with many obstacles [44,45].

3.8. PNRMA, France

PNRMA is the Natural Regional park of the Mountains of Ardèche with a surface of 1.800 km^2 in France. PNRMA is focused on the implementation of a concerted project of sustainable development, based on its patrimony protection and valorization [46].

Regarding the energy sector, the RES development within the national regional Park of the Mounts of Ardèche is already great, leaving, though, huge prospects for further growth in the future. In particular the community's territory hosts about one hundred regular and small hydro-power plants, which are producing 660 GWh per year that is twice the electricity consumption of the territory. Also, the community elaborated a wind power development guide to influence choices in the matter of wind turbine installations and development. In addition, within the framework of automatic wood energy plants promotion, 17 wood energy plants have been already installed in 15 rural municipalities representing 2.675 kW of installed capacity.

Eco-construction, wind farm and photovoltaic development, small district heating wood-energy integration and investments in renewable energy projects are some additional measures to be referred [47–51].

The communities are located in six different EU countries, namely, Austria (Murau), Cyprus (Aphrodite Hills), Estonia (Rõuge), France (PNRMA), Greece (Crete, Karditsa, Karpathos) and Italy (Cabras), with different status, development needs and priorities, facing also different energy challenges. In this respect, the application of the proposed methodology for assessing their Energy Sustainability could provide fruitful outcomes on the method's flexibility and results' validity.

Table 1
Proposed indicators.

Indicators	Measurement
Population density	Number of inhabitants/km^2
Energy consumption per inhabitant	Toe/capita
GDP per inhabitant	Thousands of euros/capita
RES production per inhabitant	Toe/capita
Fossil-fuel consumption per inhabitant	Toe/capita
RES electricity %	RES electricity production/Total energy consumption
RES thermal %	RES thermal production/Total energy consumption
RES per fossil fuel electricity production	RES electricity production/Fossil fuel electricity production
Ratio of local residents to peak season tourists %	Number of local residents to the number of peak season tourists

4. Results and analysis

4.1. Results

This section is focused on an application of the proposed methodology to the communities described above, in order to produce their Energy Sustainability Index. The application depicted in the following paragraphs is based on the communities' analysis elaborated within the framework of the following EC projects:

- Integration of Renewable Energy Technologies in Rural Insular Areas;
- RES and RUE Stimulation in Mountainous – Agricultural Communities towards Sustainable Development.

The Indicators presented in Table 1 were selected based on related review studies of the international literature [52–54], as well as consultation with local experts and administration of the examined communities, in the context of the two European Projects. Emphasis was laid on formulating a concise and transparent set of indicators, which can be sufficiently provided by local experts. It also is noted that the indicator "ratio of local residents to peak season tourists" is included in the set of indicators, so as to take into account the Seasonality, an important factor in rural communities, especially for the islands. Indeed, seasonality of demand is generally considered one of the major challenges within the tourism business, potentially jeopardizing its sustainable development.

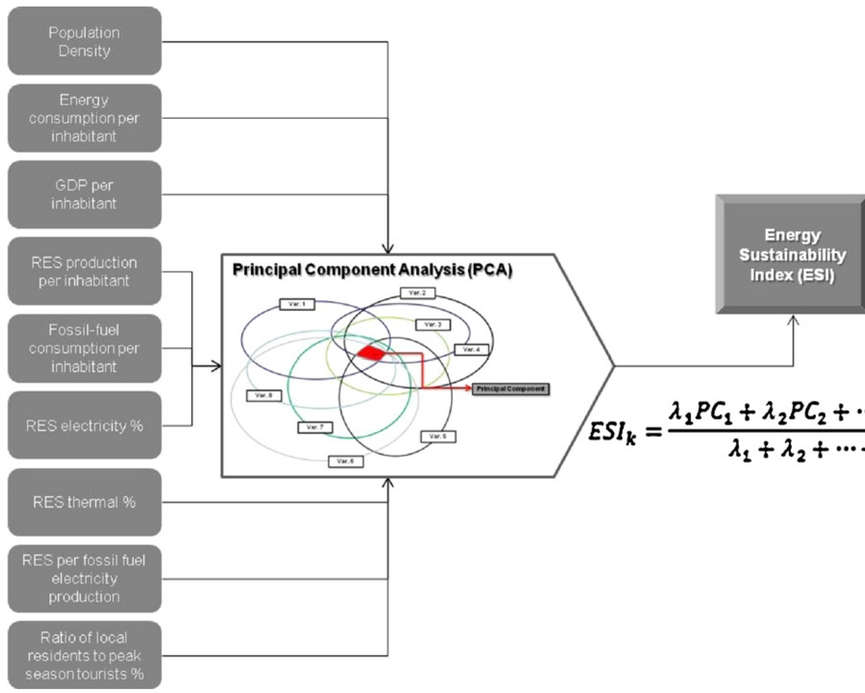
Based on the methodology described in Section 2, the nine (9) selected indicators, which quantify the concept of energy sustainability in rural communities, will be used for the development of the synthetic index (ESI) per community for the year 2009, based on the PCA (see also Fig. 1). This synthetic measure, for the time period under consideration, will:

- Capture interactions and interdependences of the selected indicators.
- Allow the monitoring of the SEAPs implementation and the related results.
- Facilitate the elaboration of "Benchmarks of Excellence" for communities that achieve a significant performance.

Table 2 displays the correlation matrix of the normalized indicators for the computation of the composite index. The data were mainly based on the Eurostat Regional Yearbook [55]. The selected indicators express the existing energy situation in the communities, the regions' energy profile and rural characteristics, as well as the available income of the inhabitants to proceed in the realization of RES and RUE measures.

Table 2
Correlation matrix.

Indicators	Population density	Energy consumption per capita	GDP per capita	RES production per capita	Fossil-fuel consumption per capita	RES electricity %	RES thermal %	RES per fossil fuel electricity production	Ratio of local residents to peak season tourists
Population density	1	0.40	−0.16	0.25	−0.39	0.29	0.20	0.24	0.69
Energy consumption per capita	0.40	1	0.09	0.69	−0.98	0.58	0.13	0.55	0.73
GDP per capita	−0.16	0.09	1	0.71	0.07	0.76	−0.55	0.80	−0.36
RES production per capita	0.25	0.69	0.71	1	−0.53	0.98	−0.12	0.98	0.35
Fossil-fuel consumption per capita	−0.39	−0.98	0.07	−0.53	1	−0.40	−0.12	−0.37	−0.72
RES electricity %	0.29	0.58	0.76	0.98	−0.40	1	−0.16	0.99	0.29
RES thermal %	0.20	0.13	−0.55	−0.12	−0.12	−0.16	1	−0.22	0.57
RES per fossil fuel electricity production	0.24	0.55	0.80	0.98	−0.37	0.99	−0.22	1	0.23
Ratio of local residents to peak season tourists	0.69	0.73	−0.36	0.35	−0.72	0.29	0.57	0.23	1



$$ESI_k = \frac{\lambda_1 PC_1 + \lambda_2 PC_2 + \cdots + \lambda_j PC_j}{\lambda_1 + \lambda_2 + \cdots + \lambda_j}$$

Fig. 1. Development of the ESI.

As shown in the table above, the indicators which incorporate RES contribution are considerably correlated in a positive manner (value of the corresponding position on the matrix close to 1), e.g. "RES electricity %" with "RES production per inhabitant" and "RES per fossil fuel electricity production". The latter is due to the low penetration of RES in the communities, with the fossil fuels having a predominant role in the production. Moreover, RES production in the majority of the communities is focused on electricity and not on covering thermal needs.

Secondly, the calculation of the eigenvectors and eigenvalues takes place. For calculating the eigenvectors and the eigenvalues the statistical program Xlstat is used. The results of the calculations are depicted in Table 3 (eigenvalues) and Table 4 (eigenvectors).

Table 3, apart from the eigenvalues, indicates also the variability of eigenvalue with the original data (variability row) and the overall variation (cumulative row) of the original that all eigenvalues contain (row-Cumulative). It is observed that the first two eigevalues include the majority of the information which is comprised in all indicators (82.129%). In addition, even though the PCA resulted in a total of seven eigenvalues, as illustrated in Table 3, only four of them are shown, comprising all the related information (98.808%). In this way, the number of variables was reduced without the loss of meaningful information.

Taking into account that eigenvectors and eigenvalues have different values, they are ordered from the highest eigenvalue to the lowest, for obtaining the components in order of significance.

Then, as mentioned in Section 2.2, the calculation of the Principal Components takes place, and the Energy Sustainability Index of each community is computed and presented in Fig. 2.

Table 3
Calculation of the eigenvalues.

	F1	*F2*	*F3*	*F4*
Eigenvalue	4.602	2.790	0.809	0.693
Variability (%)	51.130	30.999	8.983	7.696
Cumulative (%)	51.130	82.129	91.112	98.808

4.2. Analysis

According to the above table, PNRMA shows the greatest sustainability among the examined communities, followed by Murau municipality. Both these communities are characterized by the high RES penetration percentages, the relatively low population densities, while especially PNRMA has the highest performance in the GDP per capita indicator.

The third place in the communities' ranking belongs to Karditsa, a community with a very large hydro plant that covers a considerable percentage of the local needs, as well diversification in the available local resources (wind, hydro, solar, and biomass).

A lower performance is attributed to the island communities, mainly based on the significant seasonality of steep growth of the touristic and services sectors demand. This is also true, based on the international literature, indicating that seasonality has a negative impact to the ESI, causing negative economic, social and environmental impacts on a destination [56–59]. Moreover, the examined islands' unique environment and their subsequent growth of the touristic and services sectors come in direct conflict with any additional environment stress posed by the increase in fossil fuel use.

In this respect, island communities do not have great variations in their Energy Sustainability Index, fact that is mainly attributed to their more similar characteristics and thus performance in the indicators, where no significant variations per community were observed, as in the case of mountainous and agricultural communities. Among the island communities, Crete and Cabras exhibit similar performance, ranking in high places among islands. Karpathos has also a low performance among island communities, mainly due to its very low RES penetration per capita (RES production per capita indicator). The one with the lowest performance is Aphrodite Hills (Paphos), placed in the island of Cyprus, fact attributed to high seasonality observed.

The least developed community in terms of energy sustainability is Rouge, which till now has realized only small hydro plants. Biomass, used widely for heating purposes is not capable of reversing the region's overall picture, which is characterized by very low

Table 4
Calculation of the eigenvectors.

Indicators	*F*1	*F*2	*F*3	*F*4
Population density	0.212	−0.302	0.455	0.721
Energy consumption per capita	0.392	−0.231	−0.410	−0.068
GDP per capita	0.244	0.499	0.096	−0.034
RES production per capita	0.445	0.150	0.064	−0.164
Fossil-fuel consumption per capita	−0.334	0.291	0.550	−0.015
RES electricity %	0.429	0.196	0.217	−0.076
RES thermal %	−0.017	−0.428	0.461	−0.661
RES per fossil fuel electricity production	0.421	0.232	0.180	−0.072
Ratio of local residents to peak season tourists	0.265	−0.473	0.131	0.007

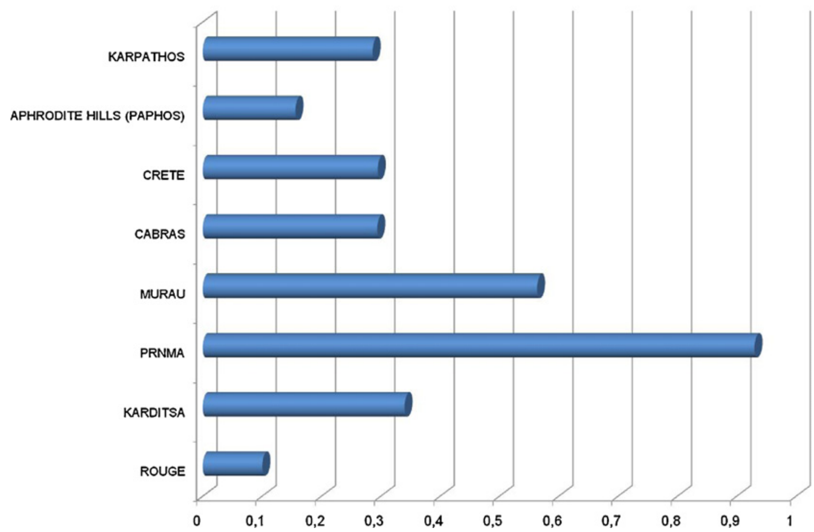


Fig. 2. ESI of the examined communities.

GDP per capita and a high energy consumption per capita, which does not coincide with the region's development rates, thus indicating large inefficiencies.

It should be kept in mind that the indicators and the performances are dependent on the communities' type and characteristics as well as their development needs and perspectives. In this respect, the presented approach can serve as the basis for the calculation of an Energy Sustainability Index for rural communities, supporting the design efforts towards the development and mainly the implementation and monitoring of such communities SEAPs.

5. Conclusions

Localizing global challenges, such as energy sustainability, is considered an issue of universal concern and paramount importance. Engaging rural communities to actions for adopting sustainable energy patterns is indeed important, taking into consideration their vast unexploited RES and RUE potential. Indeed, such communities already face particular challenges as regards growth and employment, situation that aggravated by the current financial and economic crisis.

These communities do not posse adequate capacity, in terms of necessary financial and/or human resources, to implement SEAPs. Flexible and easily used tools and methodologies are needed to support such communities' efforts for drafting action plans and monitoring SEAP's implementation.

This paper introduces the application of PCA to communities' sustainable energy planning analysis. Based on PCA, a customized methodology was elaborated for the calculation of the Energy Sustainability Index, as a weighted sum of the normalized version of a few but concise indicators for rural communities. It is important to outline that:

- The results are based on quantitative data, that can be easily measured and validated.
- Weights are calculated as the variances of the calculated PCs, avoiding thus their assignment by experts, which has subjective characteristics.

Indeed, the results of the pilot application to 8 rural communities of different characteristics, for the year 2009, are realistic and in accordance with the related qualitative studies of the two European projects, indicating PCA's applicability in such problems and is considered a step forward of the existing studies. Communities with high RES penetration percentages and development rates performed well. Based on the results, it can also be noted that the seasonality in rural tourism was sufficiently incorporated in the model, since the seasonality affects negatively the ESI of the examined communities.

The main limitation of the analysis is the usage of nine indicators in order to capture the core essence of energy sustainability. The integration of additional indicators in the synthetic index may strive towards a more precise analysis. An additional perspective is the dynamic analysis that could be performed in order to monitor the evolution of the ESI of a given rural community during periods under examination (10-year, 5-year periods), obtaining useful insights relative to its evolution.

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